Alberta ENERGY
Scientific and Engineering Services

Some Energy-Conserving Concepts for Residential Buildings

Projects supported in part by the Alberta/Canada Energy Resources Research Fund

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal, energy conservation and renewable energy and conventional energy resources. Administration for the program is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 14.

Some Energy-Conserving Concepts for Residential Buildings

Approximately 16 per cent of all the energy consumed in Canada is used to heat residential buildings. In financial terms, this amounts to many millions of dollars a year, some of which could be saved if heating requirements were reduced by incorporating energy-conserving features and devices in Canadian homes.

Beginning in 1979, several research and demonstration projects related to energy conservation in residential buildings were initiated and funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF). Three are described here.

Energy-Efficient Housing Display Program

In the early 1980s, all indications pointed to higher world oil prices and escalating costs for all forms of non-renewable energy sources. Therefore, in the belief that home builders should be encouraged to become familiar with energy-conserving building practices, A/CERRF and the Alberta Home Builders' Association (AHBA) initiated a project to build, display and monitor energy-efficient, single family homes in Alberta. All costs associated with upgrading the demonstration homes with energy conservation features exceeding the 1981 Alberta Building Code requirements were financed by A/CERRF.

In 1980/81, 10 demonstration homes were built, five each in Edmonton and Calgary. The energy-efficient construction features and appliances used in each home varied. They involved combinations of elements, such as:

- RSI 7.0-10.6 (R40-60) insulation in the ceiling/roof;
- RSI 3.5-11.4 (R20-65) insulation in the above-ground walls;
- RSI 1.8-4.9 (R10-28) insulation in the basement walls;
- air/vapour barriers and improved caulking;
- air-to-air heat exchangers;
- summer cooling fans;
- high-efficiency natural gas furnaces;
- custom window shutters;
- energy-efficient fireplaces;
- triple-glazed windows; and
- quilted roller blinds on large windows.

The heating fuel consumption of 10 energy-efficient show homes (two of which are shown here) was monitored for several years and found to be approximately 38 per cent below that of standard homes not equipped with energy-saving features.

At the time of construction, each builder estimated the amount of money and energy that would be saved versus standard housing (defined as homes meeting the 1981 Alberta Building Code requirements), as the result of incorporating these and other energy-saving components.

After most houses were sold and occupied, a two-year monitoring program was begun by the University of Calgary Kananaskis Research Centre, subcontracted to AHBA. (In some cases, monitoring was begun before the houses were sold.) Monitoring began with the 1981/82 heating season, and continued through the 1983/84 heating season, but the initial analysis of the data was limited to the period from August 1981 to January 1983.

Information about the physical characteristics of individual homes, estimates of electricity and natural gas consumption, and some indication of the energy-consuming habits of occupants formed the principal elements of the data base used in a computer analysis of each dwelling. The data base also included measurements of furnace and hot water heater combustion efficiencies, as well as information about the climate and air infiltration rates. The analysis, using computer software developed at the National Research Council in Ottawa, predicted the energy performance and costs for each home. These predictions were then compared with actual energy consumption patterns, as revealed by the information contained in utility bills.

This was not a particularly useful exercise because few trends could be observed; however, actual heating loads were higher than initially predicted by individual builders who had used relatively simple mathematical calculations to make their predictions. For some homes, in fact, the heating loads differed little from those of standard housing.

To obtain more useful comparisons, "performance indices" were calculated. These were meant to compensate for differences in house sizes, ranging from 147 to 247 m^2 (1 578 to 2 664 sq.ft.), as well as occupant habits and degree days (DD) in Calgary versus Edmonton.

Two methods were used to calculate performance indices. In the first, the amount of energy used per heated volume per degree day was calculated as $kJ/m^3/DD$. In the second method, the total thermal resistance of the building was calculated as m^2 x °C/watts. It was reported as an "effective R value."

From an analysis of this information, it appeared that some homes were more energy-efficient than others, but it was difficult to make direct comparisons among homes because some were unoccupied during portions of the monitoring period. This is worth noting because other studies have shown that the energy-consuming habits of occupants can mask the potential benefits of energy-saving components and appliances. While it was recognized from the outset that the ideal method of comparing these homes would have been to study them while they were unoccupied, it would have been completely impractical to have done so in this study, which involved homes worth a total value of approximately one million dollars.

Because the monitoring results at the end of the initial two-year period were inconclusive, it was decided that monitoring would be continued by Howell Mayhew Engineering Inc. of Edmonton, subcontracted to AHBA. This involved review and analysis of the energy performance of the 10 demonstration homes over four heating seasons, from July 1982 to June 1986. The evaluation used the HOT-2000 energy analysis computer program developed by the National Research Council and Energy, Mines and Resources Canada for homes built under the R2000 program.

Energy performance predicted by this computer program was compared with the actual performance of the 10 homes (based on utility data), and with the estimated performance of comparable homes built to 1981 Alberta Building Code requirements.

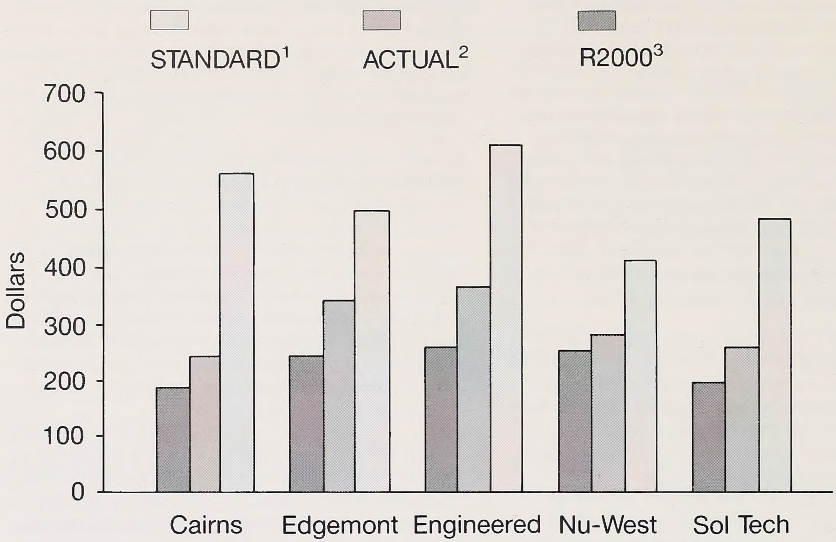
By using information about house specifications and energy performance, HOT-2000 estimates were made of the natural gas consumption for each home. These predictions were compared with actual natural gas consumption. If necessary, additional analyses were carried out to help explain any anomalies. This was followed by a computer analysis of each house as though it used insulation levels specified in the 1981 Alberta Building Code.

Design Effectiveness

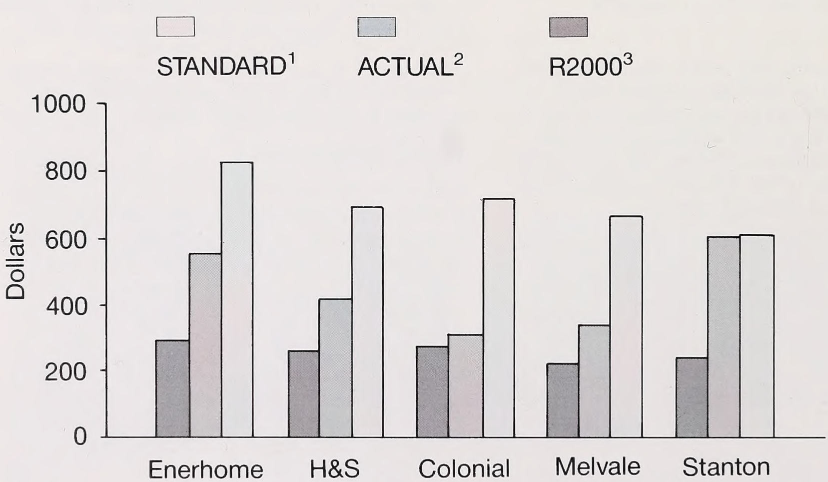
Edmonton Homes

It was found that energy consumption results from the five Edmonton homes varied widely, even though the insulation schemes were similar. This variation was thought to be caused by differences in air infiltration rates, heat-recovery ventilation, furnace efficiency and site orientation. The most energy-efficient of the Edmonton homes, the Lincolnberg Colonial, was essentially airtight, having a natural air-change rate of 0.30 an hour. It used a heat-recovery ventilator and a high-efficiency furnace. Its site orientation allowed solar gain to supply 30 per cent of its heating requirements. At the opposite end of the scale, the poorest performer, the Stanton home, had a relatively high air infiltration rate. Its natural air-change rate was 0.80 an hour. It did not use a heat-recovery ventilator. Instead, two conventional furnaces were used. Solar gain supplied only 13 per cent of its annual heating requirements.

Heating Costs — Calgary



Heating Costs — Edmonton



[1] Assuming the demonstration houses were built according to 1981 Alberta Building Code requirements
[2] Demonstration houses as built
[3] Assuming the demonstration houses were built to R2000 standards

(Source: *Energy-Efficient Housing Display Program — Final Report*, Alberta Home Builders' Association, September 1987)

Calgary Homes

The five Calgary homes had similar air infiltration rates (natural air-change rates of 0.14 to 0.36 an hour), solar gain, and heat-recovery ventilators, but differed in the use of underslab insulation, insulating windows and energy-efficient furnaces. The most energy-efficient house of the group, the Cairns home, used an insulated wooden basement floor, RSI 4.0 (R23) insulation in the above-ground walls, triple-glazed windows and a high-efficiency furnace. Extreme use of insulation in the Edgemont home (RSI 10.6 [R60] in the ceiling; RSI 11.4 [R65] in the walls) resulted in only moderate energy performance.

Comparison with "Standard" Homes

HOT-2000 analyses were made of each demonstration home, as though it had the lower insulation levels and higher air infiltration rates prevalent in 1981-era homes. The latter figures were derived from a Saskatchewan Research Council study of airtightness in 200 Canadian homes built between 1980 and 1982.

To minimize effects caused by differences in climate and house sizes, the data for these "standard" homes were normalized and expressed as joules/degree day/square metre. This was done for both the synthesized "standard" homes and the demonstration homes as they were built. The average natural gas consumption over four heating seasons was calculated. The difference between the standard version of each home and the as-built version was expressed as a percentage reduction in gas consumption. Reductions ranged from 11 to 57 per cent.

The costs to heat the demonstration homes, as well as their standard counterparts and the same houses built to present-day R2000 standards, were also calculated. While the average space-heating costs for the R2000 versions of the test homes were only 41 per cent (ranging from 33 to 61 per cent) of those for the standard homes, the actual space-heating costs of the test homes averaged approximately 61 per cent of the standard homes. However, space-heating costs for two homes were as low as 43 per cent of those for standard homes. For one home, however, they were virtually identical to those of the standard home.

Conclusions

As often happens when research work is begun in fast-developing fields, another technology emerges before the original project has been completed. Such was the case here. Since this project began in 1980/81, R2000 building concepts came to the fore and superseded some of the technologies investigated in this study. Nevertheless, the project helped home builders and home buyers become aware of, and familiar with, energy-conserving construction methods. It also contributed to the success of R2000 construction in Alberta.

Based on experience acquired since 1981, the following energy-related factors have become recognized as important when first considering construction of a house:

- geographic location;
- orientation;
- floor plan perimeter;
- attached buildings; and
- the lifestyle of occupants.

In Alberta, a minimum insulation level of RSI 3.5 (R20) should surround the house, and the following elements are strongly recommended by the Alberta Home Builders' Association:

- RSI 7.0 (R40) ceilings;
- RSI 4.4 (R25) walls;
- RSI 3.5 (R20) rim headers and foundation;
- RSI 0.9 (R5) underslab;
- RSI 2.1 (R12) doors;
- double-glazed windows;
- a mid-efficiency furnace;
- a heat-recovery ventilator; and
- low air infiltration.

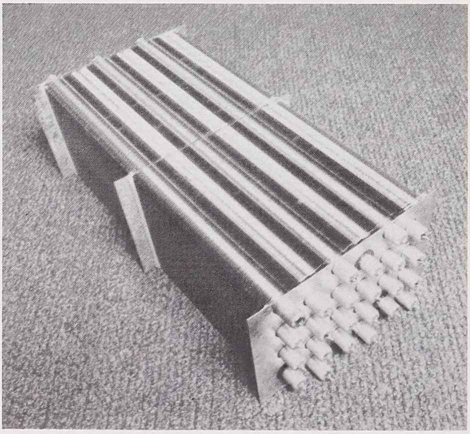
Heat Recovery Using Heat Pipe Technology

Approximately one-third of all the heat lost from older Canadian homes escapes through openings in the building enclosure, such as around window- and door-frames. Consequently, many newer homes are sealed, weatherstripped, caulked and provided with air barriers to substantially reduce this unwanted exchange of air. While this reduces space-heating costs and usually results in more comfortable surroundings, it can lead to poor indoor air quality and structural damage caused by high levels of humidity.

To overcome these problems and still maintain lower energy costs, heat-recovery ventilators (sometimes called air-to-air heat exchangers) are used to provide ventilation, while recovering some of the heat contained in the exhaust air during the heating season.

In recent years, heat pipe technology developed for the American space program has proven to be a reliable and simple means of transferring heat over short distances. Therefore, it was suggested that an air-to-air heat exchanger using heat pipes might represent an improved and cost-competitive product.

From 1984 to 1987, development and testing of such a product was carried out by EMC Energy Management Consultants Ltd. (EMC) of Calgary.



Heat pipe units (as shown here) were used in prototype air-to-air heat exchangers designed and built by EMC Energy Management Consultants Ltd. of Calgary.

Design Concepts

In its simplest form, a heat pipe is a finned tube, sealed at both ends, from which air has been evacuated and to which a small amount of liquid refrigerant has been added. The pipe is usually inclined at a slight angle, causing the liquid to remain in the bottom of the tube.

When heat is applied to the bottom end, the liquid refrigerant vapourizes and moves to the top end of the tube. Here, in the process of cooling, the refrigerant releases its heat of condensation into the surrounding air and condenses. The liquid condensate then flows to the bottom of the tube to repeat the process.

When a heat pipe is used in an air-to-air heat exchanger, the warm exhaust air from a house is passed over the lower end of the heat pipe, causing the refrigerant to evaporate. This allows cold incoming air to be warmed at the condenser end of the heat pipe.

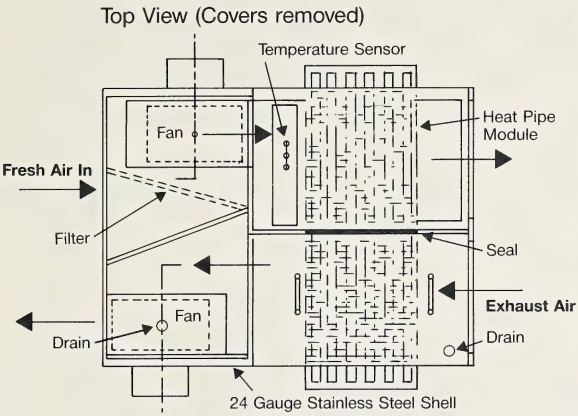
By tilting the heat pipe in the opposite direction during the summer, warm incoming air can be cooled. This ability to also provide some cooling during warm weather distinguishes heat pipe technology from conventional heat-recovery ventilators.

An air-to-air heat exchanger was designed by EMC, comprising a heat pipe module, a supply fan, an exhaust fan and a control system within a sheet metal enclosure measuring 66 cm (26 in.) long, 47 cm (18.5 in.) high and 30 cm (12 in.) wide.

Foam weatherstripping and maintenance of a slightly higher air pressure at the supply end of the unit were used to prevent air from bypassing or leaking from the exhaust end to the supply side. Both the supply air and exhaust air were filtered. Provision was made to easily remove the heat pipe module for cleaning.

Controls consisted of three thermostatically operated switches with remote sensing bulbs, a humidistat, two-speed controls, a relay, a control power transformer, indicating lamps, a fuse and switches. Also, frost protection was provided at the exhaust end to avoid any loss of ventilation capacity in extremely cold weather.

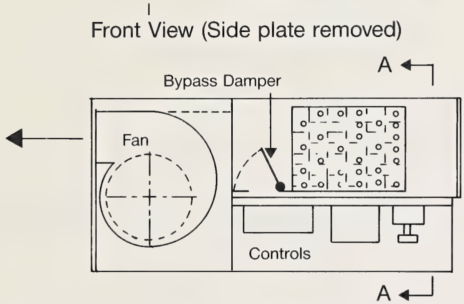
Heat Pipe Heat Exchanger

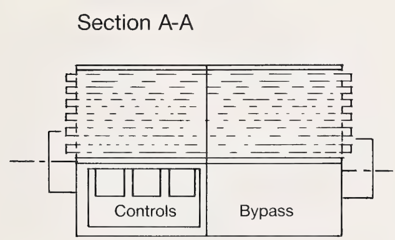


Notes:
- Heat pipe module to be easily removable for cleaning.
- Fan compartment to be detachable.
- Bypass damper to be solenoid-operated from sensor for defrost.
- Unit to be tilted for summer/winter operation.
- Filter in air inlet.

Heat Pipe Module
Core: 19.8 cm (7.8 in.) Wide, 15.2 cm (6 in.) High, 45.7 cm (18 in.) Long.
Aluminum heat pipes with continuous aluminum fins.

Fans
2 fans with variable speed control 0-6.7 m^3/min (0-235 cu. ft./min)





(Source: *Residential Air-to-Air Heat Exchanger Using Heat Pipe Technology*, EMC Energy Management Consultants Ltd., May 1987)

Four prototype units were built, comprising two early development models and two test units. One of the test units was installed in an 84 m^2 (900 sq.ft.) Calgary home for summer and winter testing under typical residential operating conditions, while the other unit was tested at the Ontario Research Foundation in Mississauga, Ontario.

Field Testing

The home in which one unit was field-tested was specifically chosen because it had been renovated and made airtight, but was experiencing excessive levels of humidity during cold weather. For example, to ventilate the house and allow humidity to escape on the coldest days, it was necessary to open the windows.

During the test period, from December 1985 to September 1986, the test unit's fans were operated at low speed only. This provided an air-change rate of 0.56 an hour, which adequately reduced and controlled humidity at levels acceptable to the homeowners. At no time during the test was condensation observed on the windows, even when outdoor temperatures were as low as -38°C (-36°F). Airflow measurements indicated an average 51 per cent recovery of sensible heat, but wintertime heating costs were lowered by only $26.

Ontario Research Foundation Tests

The airflow rates, cross-leakage and heat transfer performance for one unit were measured at the Ontario Research Foundation in accordance with Preliminary CSA Standard C439-M1985 "Methods of Testing for Rating the Performance of Heat Recovery Ventilators."

The test results showed that recovery of sensible heat ranged from 53 to 58 per cent, which was in the middle of the range of values measured for conventional air-to-air heat exchangers. Airflow rates and cross-leakage results were also in the mid-range of values. The tests showed that minor design changes would allow the overall heat-recovery rate to be increased to approximately 68 per cent.

Conclusions

It was expected that commercial manufacture of improved units would result in products that retailed for approximately $1 000. This would be in the mid-range of prices charged for conventional heat-recovery ventilators and could be lowered if heat pipes were available from several suppliers instead of only one. However, the purchase costs could not be justified solely on the basis of reducing space-heating costs. Other factors, such as the ability to lower humidity levels and have more comfortable surroundings, should be considered. Nevertheless, the project demonstrated that heat pipe technology offers several advantages over the conventional designs of air-to-air exchangers, such as:

- simple construction;
- the use of reliable, long-life heat pipes which do not have any moving parts;
- smaller size; and
- summertime cooling.

Although EMC Energy Management Consultants decided it would not be appropriate for them to begin commercial manufacture of the product at this time, established manufacturers might wish to consider adding it to their product line.

An Energy-Efficient Masonry Fireplace

In the past, wood stoves or fireplaces installed in homes drew their combustion air from within the building. This created a partial vacuum inside the house and caused cold outside air to enter the building through openings around doors, windows and other structural components.

In tightly sealed homes, where few opportunities exist for outside air to penetrate the structure, replacement air can be drawn down the chimney, causing combustion gases such as carbon monoxide to be vented into the house.

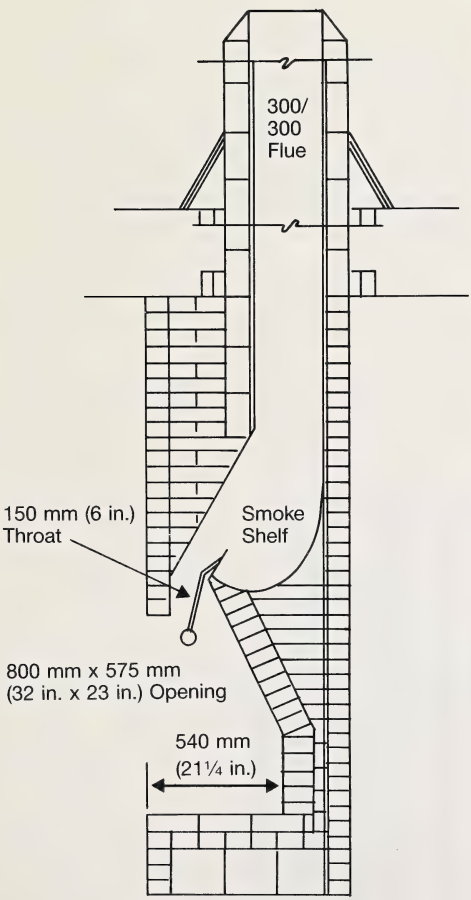
While wood stoves of various designs have become available in recent years, and metal fireplace and flue units are fairly common in moderately priced homes, the design of conventional masonry fireplaces has remained virtually unchanged since the 18th century. Although some 3 500 to 4 000 masonry fireplaces are installed annually in Alberta homes, they are often poorly designed and cannot heat even the room in which they are located. In fact, the amount of previously warmed air drawn by a fireplace from within a house and up the chimney is often greater than the quantity of warm air expelled by the fireplace into the house, making some designs net energy wasters. Furthermore, when the fireplace is not operating, poorly fitted dampers in the flue allow cold air to enter the house or warm air to escape.

To help overcome these deficiencies, staff at the Centre for Research and Development in Masonry (CRDM), associated with the University of Calgary, designed an improved masonry fireplace in 1979. They received some financial assistance from A/CERRF in 1982 to test this design versus conventional masonry fireplaces.

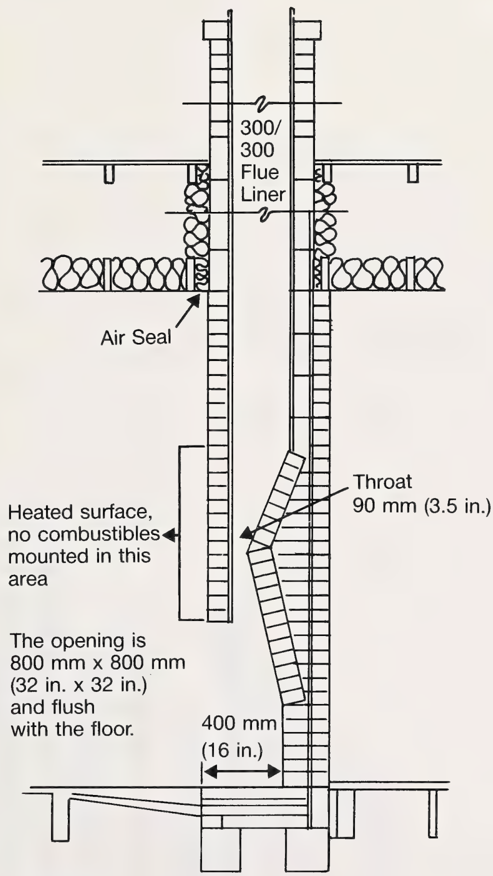
Fireplace Design

Several design elements incorporated into conventional masonry fireplaces contribute to poor performance. For example, the deep, nearly square, firebox allows only a small fraction of the potentially available radiant energy to be emitted into a surrounding room. Instead, it is expelled up the chimney or conducted through the masonry to the outside. Also, masonry fireplaces are fitted with a damper in the narrow throat above the firebox and at the entrance to the flue. Usually this damper provides a poor seal against incoming air and allows warm room air to escape up the flue.

Construction Details for Conventional Fireplace and CRDM Modified Fireplace



Conventional



Modified

(Source: *Energy-Efficient Masonry Fireplace: Design and Performance Evaluation*, Warren, D.J., Centre for Research & Development in Masonry, November 1983)

After identifying the causes of deficiencies in fireplace designs, CRDM staff designed and built a modified masonry fireplace, which differs from the conventional design as follows:

- the firebox depth in the modified design is 400 mm (15.8 in.), as opposed to 540 mm (21.3 in.) in the conventional design;
- the side wall splay angle was increased from the usual 5° for the conventional design to approximately 30° for the modified design;
- the firebox frontal area of the modified unit is 6 585 cm^2 (1 021 sq.in.), whereas in the conventional design it is 4 903 cm^2 (760 sq.in.);
- the damper face area in the modified design is smaller; 650 cm^2 (100.8 sq.in.) versus 753 cm^2 (116.7 sq.in.);
- the smoke shelf present in conventional fireplaces was completely removed from the modified design; and
- the front face of the modified unit was reduced in thickness from 20 or 31 cm (8 or 12 in.) to 10 cm (4 in.).

Some of these changes are meant to increase the transfer of radiant heat, while others were intended to improve the draft and reduce the chance of smoke entering the house.

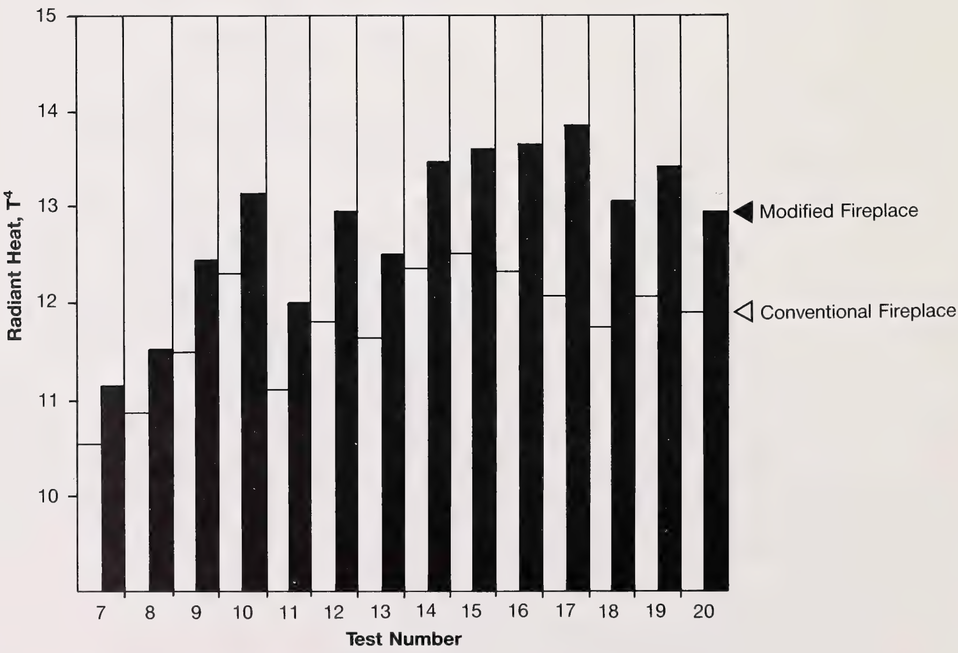
Relative Performance Tests

Specially constructed rooms were built at CRDM to separately house a conventional and a modified fireplace. The rooms and the fireplaces were equipped with instruments to measure temperature at various locations, radiant heat output, pressure differences and the rate of airflow into the room and up the chimney.

Twenty tests were performed under a variety of outdoor conditions of temperature and wind velocity, and the relative efficiency of one fireplace versus the other was calculated.

When the outdoor air temperature was 0°C or lower, the modified fireplace was found to be 52 per cent more efficient than the conventional unit, but at temperatures above 10°C (50°F), there was only a 12 per cent improvement in efficiency.

Radiant Heat Measurements:
Conventional Fireplace vs. Modified Fireplace



(Source: *Energy-Efficient Masonry Fireplace: Design and Performance Evaluation*, Warren, D.J., Centre for Research & Development in Masonry, November 1983)

Overall, the radiant energy emitted by the modified unit was approximately nine per cent greater than the conventional fireplace.

Other conclusions drawn from this investigation and supported by information in the literature were:

- the transfer efficiency of a fireplace is proportional to the height of the frontal opening. A lower vertical opening of the firebox decreases the amount of emitted radiation;
- restricting the throat of a fireplace can contribute to fireplace efficiency;
- the horizontal smoke shelf causes eddy currents in the escaping combustion gases and serves no useful purpose in the performance of a fireplace;
- any abrupt changes in the direction of combustion gas flow, caused by design features, are detrimental to the efficient performance of a fireplace and can cause smoke to enter the house;
- increasing the transfer of convection heat from the fireplace to a room through the use of forced air heat exchangers can increase the transfer efficiency of the fireplace; and
- the use of air ducts to supply combustion air to a fireplace can improve performance and efficiency.

Fireplace Retrofits

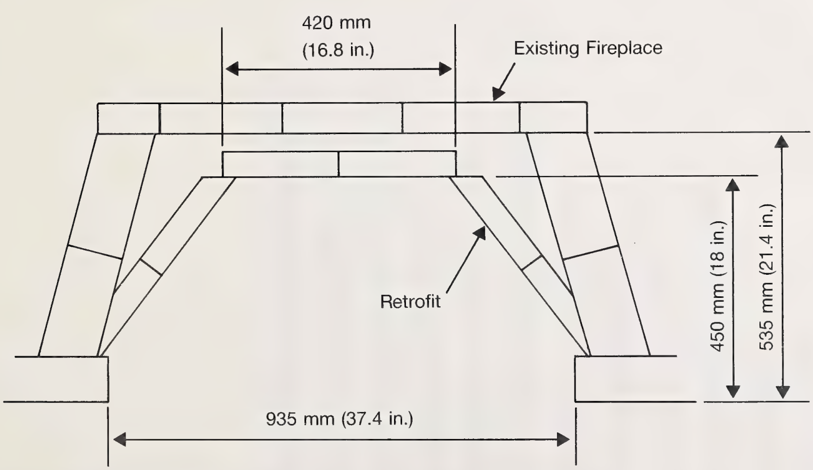
In addition to comparing the modified fireplace with the conventional design, two methods of retrofitting a conventional fireplace were tried and tested. In one, 50 firebricks were used to reshape the firebox by increasing the splay on the side walls and decreasing the depth. In the second retrofit, 35 firebricks were used, but only the side wall splay was increased.

Measurements of radiant energy emitted by the retrofitted fireboxes showed that both retrofits were an improvement over the conventional design. On average, the side walls emitted 3.3 per cent more radiation, while the back walls emitted 14.9 per cent more.

Other methods of improving fireplace efficiency were tested. For example, the addition of a damper at the top of the chimney successfully prevented the loss of warm room air up the flue and prevented cold air from coming down the chimney and into the house.

Glass doors installed across the front of a fireplace opening will reduce the loss of heated room air to the outside, but unlike the use of a top damper,

Conventional Fireplace Retrofit



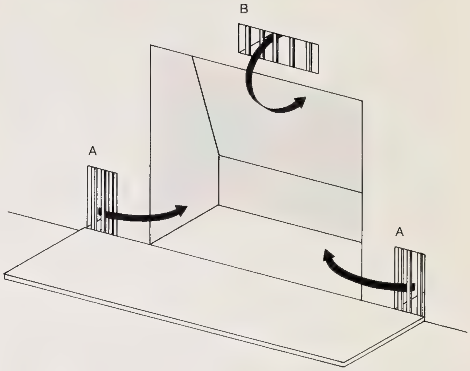
A conventional fireplace was retrofitted with 50 firebricks to increase the side wall splay and decrease the firebox depth.

(Source: *Energy-Efficient Masonry Fireplaces*, Warren, D.J., Centre for Research & Development in Masonry, September 1983)

they will not prevent cold air from entering the chimney. When glass doors are closed during the operation of a fireplace, they reduce the amount of radiant energy emitted into the room and restrict the entry of combustion air into the fireplace.

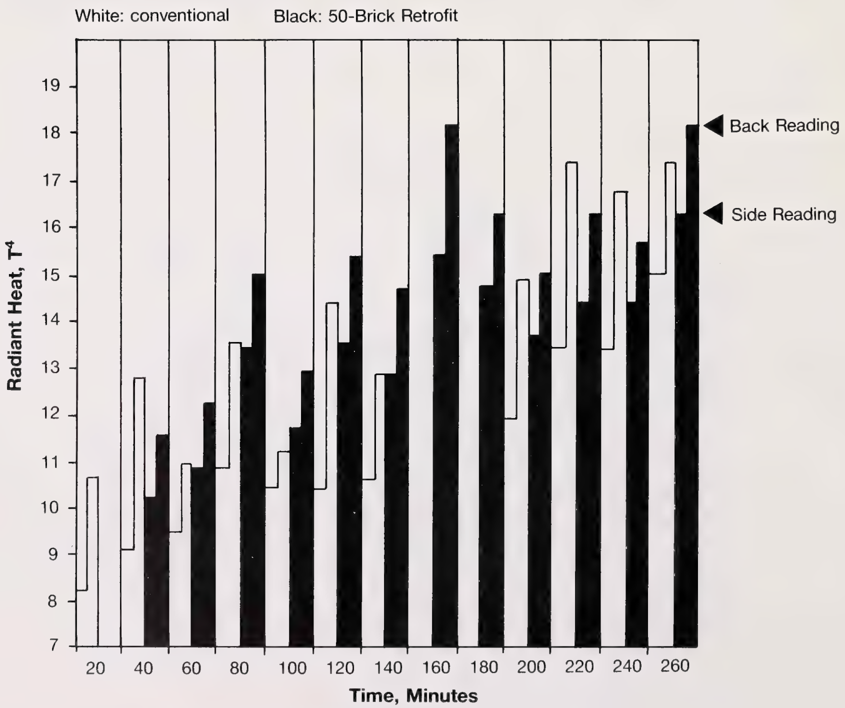
CRDM staff designed a system of using air ducts to deliver outside air to the vicinity of the fireplace and recommend this procedure over the use of glass doors. (The Alberta Building Code now stipulates that all wood stoves and fireplaces must have their own combustion air supply.) The CRDM air duct design is described in the publication, "Fresh Air Intake for Fireplaces," available from Alberta Municipal Affairs, Housing Division.

Positioning of Fresh Air Supply for Masonry Fireplaces



(Source: *Energy-Efficient Masonry Fireplaces*, Warren, D.J., Centre for Research & Development in Masonry, September 1983)

Radiant Heat Measurements:
Conventional Fireplace vs. 50-Brick Retrofitted Fireplace



(Source: *Energy-Efficient Masonry Fireplaces*, Warren, D.J., Centre for Research & Development in Masonry, September 1983)

Efficiency Tests

The final task carried out in this project was the evaluation of several methods of testing the efficiency of wood stoves and open fireplaces. CRDM staff chose the Electric Co-heating Method developed by the Lawrence Berkeley Laboratory in the United States. This technique is based on the principle that the net heat gain resulting from the operation of a fireplace will result in a decrease in the energy required by electrical heaters to maintain a constant indoor temperature in a test building. The net efficiency can be calculated by measuring the wood energy consumed by the fire and the decrease in electrical energy. Tests are usually done at night to avoid the possible influence of solar heating.

Subsequent Developments

This body of work and studies performed by CRDM staff on behalf of other agencies led to research on the safety and deterioration of masonry chimneys, contributions to the standards of operation of masonry fireplaces, and some assistance to A/CERRF in developing an understanding of the heat transfer mechanisms within the masonry walls of buildings. In 1984, however, CRDM was disbanded.

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Details about the use of heat pipe technology in air-to-air heat exchangers are available from:

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Additional copies of this publication are available from:

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